Ant. VII-On the Application of Galvanic Electricity to Practical Astronomy. By R. J. L. Ellemy, Esq., Government Astronomer.
[Read before the Royal Society, August 27, 1860.]
Tue application of electro-dynamics to astronomical purposes presents one of the most marked features in the history of modern astronomy ; and it is probable that without the assistance of the electric current, no improvements that could be devised in the optical construction of the instruments used would secure the almost absolute precision we can now attain in those observations in which the accurate determination of time is of primary importance.

The application of electro-dynamics, styled indifferently chronography and galvanic registration, has resulted in such decided adrantages in the great American and European observatorics, into most of which it has been introduced, that no observatory of any preteusions can be considered complete without it.

The aim of my paper this evening is not so much to enter upon the history and successive improvements made in this application of electricity, as to describe to the society the manner in which it has been adopted in the Astronomical Observatory of this colony, and especially to call attention to a recently constructed chronographic apparatus, which will be of great assistance in making the astronomical observations in comnction with the geodetic survey.

The first use of the galvanic current in astronomical ob)serving was made by Professor Locke, of the United States, as early as 1849, and although its successive adoption in various observatories has led to many improvements and modifications of the original mechanical arrangements, the principle remains the same. The general form of the apparatus may be deseribed as consisting of an electro-telegraphic register, with a double system of electro magnets and indenting styles, each systom haring a separate galvanic circuit.

The chronographic apparatus now in use at the Astronomical Observatory may be thus described :-

The register, with the exception of its possessing a double
system of electro magnets and levers, is in all respects similar to Morse's Telegraphic Recorder, which is the instrument used in the telegraph offices in this colony. By means of a weight and regulating train of clock-work, a fillet of paper is kept moving between two small rollers at a pretty uniform rate of an inch per second; and the armatures and levers are so arranged, that, when acted ou by the electro magnets, they indent the paper as it runs between the rollers in parallel lines, about half an inch apart. The indenting styles are placed in a line perpendicular to the margin of the fillet, so that if the action of the two electro magnets be coincident, the two indentations will be exactly in tha same point with relation to the length of the paper. The clock-work is wound up by a key, but there being no maintaining power, this cannot be done during the working of the apparatus. The regulation of the train is attained by a simple "fanfly," and can be stopped at any moment by means of a catch pressing against the fly arbor. The clock-work will run regularly for a quarter of an hour.

The voltaic circuits, for working the electro magnets, are two : the clock circuit, and the observing circuit.

The observing circuit is thus arranged, a battery of three cells of Daniel's or Smee's combination being generally used for producing the currents. From one pole of the battery a wire is led to one terminal of the electro magnet of the circuit, from the other terminal a wire is led to the purs of the transit instrument, and then up the side of the purs to wooden frames fitting round them, where it is comected with an insulated portion or anvil of a small telegraphic key; a wire attached to the other portion, or hammer of the key, is led to the opposite pole of the battery, and thus, with the exception of the interval between the hammer and the anvil of the key, the circuit is complete. A slight pressure of the finger on the key will complete the ciscuit, when the electro magnet attracting the armature, causes the style to indent the paper. The indentation, when the paper is in motion, will be in the form of a dot or a stroke, as the pressure on the key is momentary or prolonged. The keys are so arranged that in whatever position he may be observing, there is always one convenient to the right hand of the observer.

The clock circuit, which includes the astronomical clock, is double, in consequence of the necessity of introducing what is known as a relay magnet, whose office will be presently described.

From one pole of a three-eclled battery a wire is led to a terminal of the electro-magnet of the clock circuit, and a wire also connects the other terminal with the relay, where it ends in a platinum point on the top of the armature lever; the other pole of the battery is comnected directly with the relay, and ends also in a platinum point, close and opposed to the other. The cirenit of this system is therefore incomplete ouly by the separation of the two platinum points above mentioned, which are kept apart by means of a delicate spring. The second circuit includes the clock contact apparatus, and the delieate clectro magnet of the relay, and may be thus traced :-A pole of a single ecll hattery is connected by a wire directly with onc of two springs, which are a portion of the contact apparatus of the astronomical clock; the other pole is connceted to one terminal of the relay magnet coil, whose other terminal is connected by a wire with the second spring of the elock contact; this circuit then is only incomplete by the separation of the two springs.

The "clock contact" is thus arranged :-An extra wheel of sixty conical teeth is fixed in the escape whed arbor of the astronomical clock; a delicate spring, with a jewelled pallet, is so placed that when the elock is at rest the pallet drops into the angle between the teeth; at the back of this spring is a little platinum stud; another spring, with a platinum stud, is placerl just bchind this, and is so adjusted that a slight lifting of the front spring brings the two platinum studs into contact.

When the clock is going, the escape wheel revolves once in a minute, and the extra wheel moves one tooth each sccond, which in passing presses against the pallet, and lifts the spring just sufficiently to bring the studs into contact for an instant, and so on for each second. One of the teeth of the contact whecl is filed down, so that it passes without lifting the spring, and the scconds' hand is so placed that it points at 60 on the dial when this short tooth comes to the pallet. The two springs are firmly but separately attached to a block of insulating matcrial, which is itself screwed to the front plate of the clock, so that the springs are insulated from the clock works and from each other. There are screw adjustments for regulating the lift of the front spring and the distance between the studs.

The olject of introducing a relay magnet into the elock circuit is to avoid the oxydization of the platinum studs in the clock contact, which would result from using directly a battery
sufficiently powerful to work the register magnet. The oxydization would give rise to imperfect contact, and the necessity of frequently disturbing the clock works in order to re-polish the springs, which of course should be avoided if possible.

The operation of the clock circuit will now be readily understood. The "contact" being made every second by the clock itself, the current from the one-celled battery causes the relay magnet to attract its armature, thus bringing the two platinum points of the relay before mentioned into contact; the contact completes the circuit from the battery to the clock register, whose magnet immediately attracts the armature and lever, causing the style to indent the paper. This action being repeated every second, coincidently with the oscillations of the clock pendulum, if the paper be put in motion, a series of dots about an inch apart is made on it as it passes through the rollers, every sixtieth dot being left out by reason of the short tooth in the extra wheel, this serving to mark the commencement of each minute.

The following is the mode of observing with this instrument, as practised in our Observatory :-

After seeing that the circuits are complete, the register and relay in good adjustment, and the seconds' dotsbeing plainly indented on the paper, the observer proceeds to make his observation. Let it be, for instance, the transit of a star over the wires of his transit instrument:-The instrument being in position, and the observer seated at the transit instrument, he watches for the stars' approach to the first wire; when near it, he releases the detent of the clock train of the register, and the paper commences to move through the rollers indented at cach second by the clock circuit. Immediately the star appears behind the wire, he touches the key for an instant, and the style of the observing circuit indents the paper; he does this for each wire, until the observation is complete, when he stops the chronograph-always taking care before he stops it that a minute space has occurred on the paper during the observation, in order that the seconds may be dated; if it has not, he must let it run till one occurs ; and it is usual to mark this space with the number of the minute at once, to facilitate "reading off," as well as to indicate by a number or symbol the object obscrved. Of course, if several observations are being made in quick succession, the instrument is not stopped till the series is complete.

It is the custom at the Observatory to "read off", every morning, unless the result of any observation be required at
once, the fillet used in the previous night's work, and with a needle point puncturing in the lines of seconds perpendicular and corresponding to each dot made by the observer's circuit. The scconds' dots are then comed from the minute spaces; the number of the second dot preceding auy purcture is noted, and the fraction represented by the position of the puncture with relation to the dot is measured by a small transparent conical scale, by which means any little irregularity in the length of the seconds' spaees is rectified. The "reading off" is directly transcribed into the transit-book.

The usual mode of observing without the chronographic apparatus is styled the eyc-and-ear method, and a short description of it will at once make the superiority of chronograply obvious.

In observing by the eye-and-ear method, the clock or chronometer must be in such a position that the movements of the hands on the dial shall be risible, and the "beats" of the pendulum or balance distinctly audibie to the observer. Shortly before the occurrence of any astronomical phenomenon, such as the transit of a star, he observes the time of the clock, "taking up" the beats, mentally counting them until the star passes the first wire, when he writes down on his observing slip the corresponding seconds indicated ; and if it occurs between any two consecutive seconds, he estimates as nearly as he can the fraction of a second also. For a complete transit, this has to be done over several wires, writing down the times between each observation. It has been found that 15 seconds are required to observe and record for cach wire, and to "take up" the "beats" again without hurry. The wires, thercfore, are generally arranged so that an equatorial star shall take 15 or 16 seconds to pass from one to another. The time required to complete a transit observation over seren wires of a star haviug a declination of 4.5 degrees, is over two minutes; and the utmost precision that can be attained by the best observers, under the most farorable circumstances, in a mean of seven wires, is limited to one-tenth of a second, and it is very much to be doubted if anything near this precision is ever attained.

Two different observers will seldom agree as to the exact instant of a transit or occultation, owing to what is known as personal equation, the precision of combining the visual impression of the observations with the sound of the elockbeats depending moch on the age, temperament, and health of the olserver. When several individuals, therefore, are
employed in an observatory, it becomes a matter of the first importance to determine their personal equations, in order that all observations may be reduced to a standard.

In the chronographic method no listening to the clock is required-the clock may be in another apartment, if neces-sary-no recording by the observer during the observation is needed, so that the intervals between the wires may be reduced from fifteen to three seconds ; the observer's attention can be entirely confined to the observation itself, and is not distracted between observing, listening, and writing, and the precision attainable is at least ten times as great as by the old method. Personal equation is greatly reduced, if not eliminated.

Any one acquainted with the principles of physiology will at once perceive the great superiority of the chronographic registration over the eye-and-ear method. In the latter we have two totally distinct external impressions, the view of the star crossing the field of the instrument, and the sound of the clock-beats which require to be mentally counted at the same time; while in the method now adopted we have only the one external impression-the view of the star. The mental operation involved, in coinciding thus with the touch of the finger on the key, being so rapid as to be almost inappreciable.

Again, the record on the register-paper is permanent, and in case of an error in transcribing, can be afterwards referred to; whereas there is nothing but the memory to fall back upon in case of an erroneous record by the eye-and-ear method. The amount of observing in a given time can be nearly ten times as much, and with very little labor to the observer. In cataloguing stars this becomes a great object.

One clock is sufficient for any number of instruments ; and in our Observatory we use the chronograph not only for the transit but for prime, vertical, and other extra meridianal observations, by leading wires from the observing circuit to the different instruments used. Wires are also carried from the Lighthouse, where, by means of a key, observations which are being made for the astronomical ayzmuths of the different trigonometrical stations can be directly recorded on the chronographic paper, so that the otherwise troublesome and often difficult determination becomes as easy and precise as observations made in a fixed observatory.

Considering the benefits derived from the adoption of chronographic registration in our permanent observatory, I
was anxious to devise some means by which it could also be adapted to the shifting observatories used in the geodetic survey. Ifere, large clocks being of course out of the question, the great difficulty was the mechanical arrangement by which the "elock contact" could be made with an ordinary marine chronometer-a difficulty so great that, so far as I am aware, it has not been previously orercome. After several experiments I was enabled to plan an appliance, which has been admirably constructed by a watchmaker at Williamstown, and is found to work perfectly, without interfering with the rate of the chronometer. It consists of an extra wheel, of 60 teeth, which is in the seconds' arbor, the tecth conical, with a slight rake, and, as in the astronomical clock, one tooth is cut out as a minute data. The great delicacy required iu adapting contact springs, without producing undue friction, offered the chief obstacle; but by placing the opposing surfaces of the teeth and pallet at the most farorable angle, and arranging so that the slightest lift of the pallet broke contact, instead of making it, the principal difficulty was overcome. The contact here is the reverse of that in the clock; for when the pallet is in the angle between two teeth, the spring buuks on a platina stud, and the contact is complete ; but each passing tooth lifts it sufficiently to break contact for an instant. This peculiarity would, of course, eause a registering style to make a long stroke and a short space ; but the same cffect as in the "clock contact" can be attained by a modified relay, or reversed lever in the register.

The success of this appliance to a chronometer at once admits of a perfectly portable chronograph being arranged, and 1 have had a register constructed to complete the apparatus.

The fillet-paper used in the Observatory, although offering several advantages, would be very inconvenient for a portable chronograph; the plan of the register, therefore, is different altogether to the one in the Observatory.

A metal drum, six inches in diameter, and eight in length, corered with fine cloth, is made to revolve on a horizontal axis in about 35 scconds, by means of a weight and clockwork, regulated by a conical pendulum. A small waggon or carriage is made to traverse smoothly and easily on a railway, in a direction parallel to the axis of the drum: this earriage carries the electro-magnets, levers, and styles, which are so adjusted that when the electro-magnets are brought into action, the styles will impinge on the drum. The move-
ment of the waggon is regulated by the clock-work, and during the working of the apparatus it progresses on the rail about a quarter of an inch for every revolution of the barrel.

In using the apparatus, the drum has to be covered with a proper sheet of paper, which is fitted on damp, the joining edges being gummed together with isinglass. To do this conveniently, the drum is made so that it can be removed from its bearings very readily. When the paper is dry, and all the connections and adjustments made perfect, the instrument is ready for use. On setting the train in motion, the drum will revolve slowly and uniformly on its axis, and the waggon, with its electro-magnets and styles, also moves in the direction of the barrel axis. The two circuits are similar to those in the Observatory, and require no further explanation.

One style punctures the seconds transmitted by the chronometer circuit, the other punctures the observation record; and the two sets of punctures are distinguished by their size. The relative motions of the drum and waggon causes the two series of punctures to assume the form of a spiral line around the cylinder. In order that the styles may not stop the cylinder, if they happen to remain in the paper for a longer time than is required, they are allowed to follow the motion of the cylinder a little, but when they are withdrawn from the paper, by means of a spring, they immediately resume their proper position.

The reading off is performed in a similar manner to that of the fillet register, but it is necessary to remove the paper from the cylinder before this can be done.

In conclusion, I would remark that there is nothing original in the chronographs used at the Observatory, the clock contact being very similar to the one used at Greenwich, and the register is of the most usual form. The portable chronograph, as far as the register is concerned, is a modification of onc lately made for the Altona Observatory, the chronometer contact being the only portion which, I believe, has any claim to originality.

